Synthesizing Sounds from Physically Based Motion

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Introduction

- Goals
  - Generate audio from physical simulation
  - General purpose method
  - Same simulation as used for visuals
  - Low additional overhead
- Same motivation as for physically based animation

Related Work

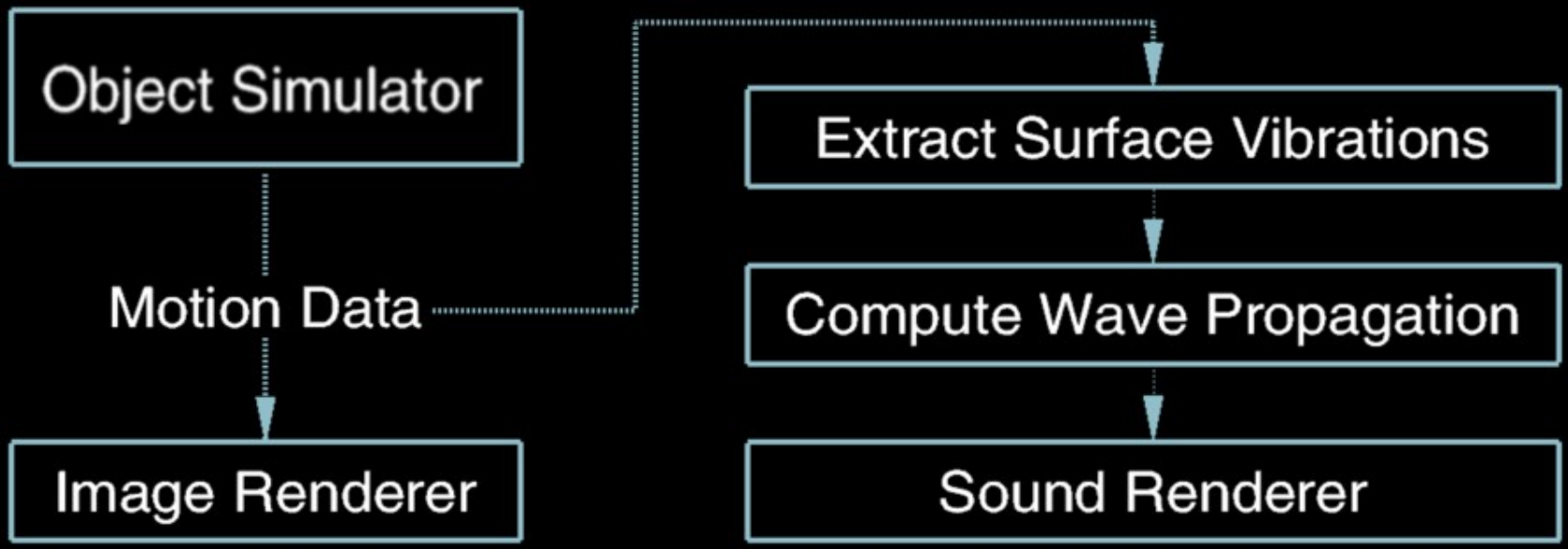
- **Work in Graphics Community**
  - Graphics and Sound

    Hahn *et al.* 95, Takala & Hahn 92
  - Sound Propagation

    Funkhouser *et al.* 99 & 98, Min & Funkhouser 00, Monks *et al.* 00, Tsingos *et al.* 01
  - Simulated Sound

    Terzopoulos & Fleisher 88, van den Doel & Pai 98, van den Doel *et al.* 01
- **Other work in Digital Sound/Music (please see paper)**

Overview


Object Simulator
Motion Data
Image Renderer
Extract Surface Vibrations
Compute Wave Propagation
Sound Renderer

Simulation Requirements

- Temporal Resolution
- Dynamic Deformation Modeling
- Boundary Representation
- Physical Realism

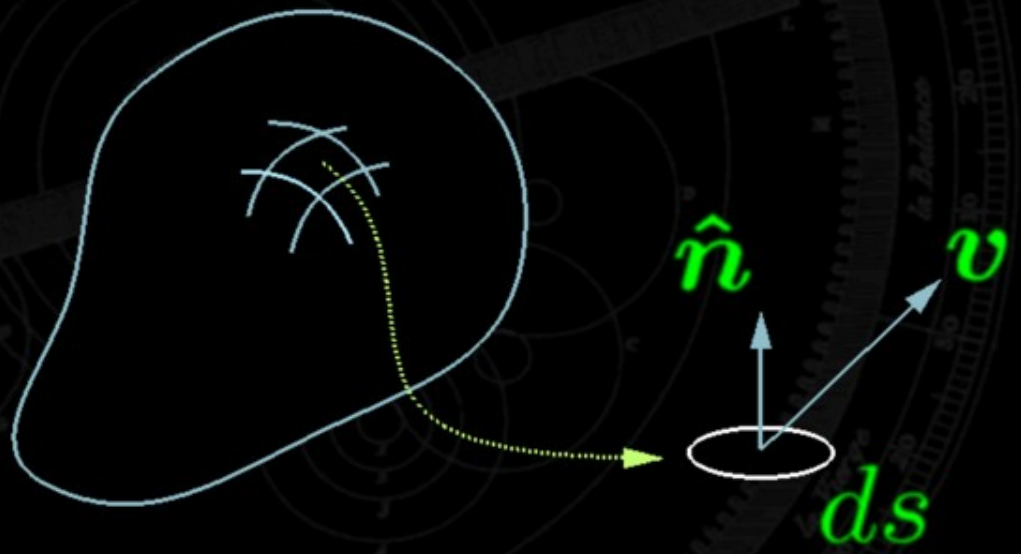
Simulation Method

- Tetrahedral Finite Elements
  - Linear basis functions
  - Green's Strain
    (non–linear, finite deformation)
  - Rayleigh Damping
  - Explicit time integration
  - Details in O'Brien & Hodgins (SIGGRAPH 99)

Surface Vibrations

- Relate surface movement to pressure

$$p = z\boldsymbol{v} \cdot \hat{\boldsymbol{n}}$$



$$z = \rho c = 415\,\mathrm{Pa} \cdot \mathrm{s/m}$$

Specific acoustic impedance

- Approximate p as const. over triangles

Surface Vibrations

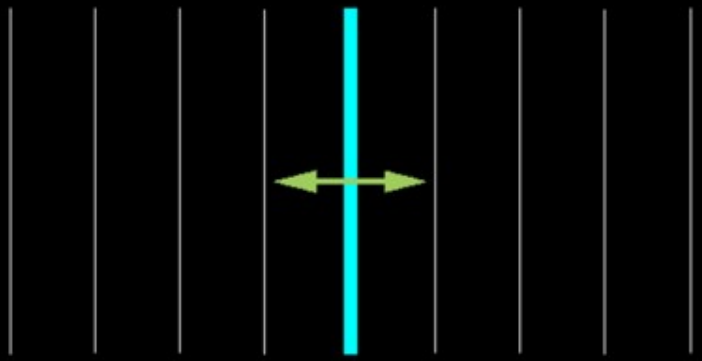
- For each triangle, band–pass filter to remove info outside audible range
  - Low–pass with windowed sinc function
  - High–pass with DC–Blocking filter
- Result: pressure as piece–wise const function over the surface(s)

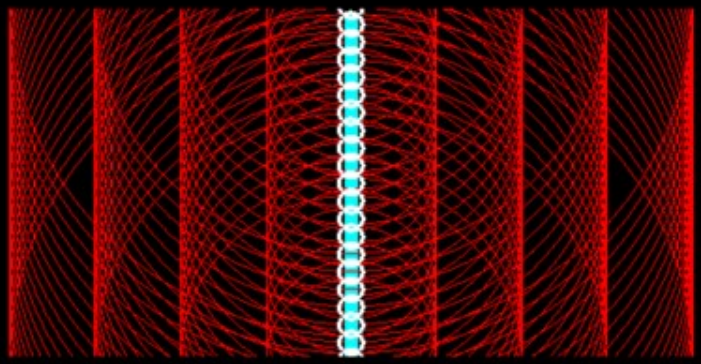
Radiation and Propagation

- Ignore reflection and diffraction
- Account for visibility
- Account for distance falloff

Radiation and Propagation

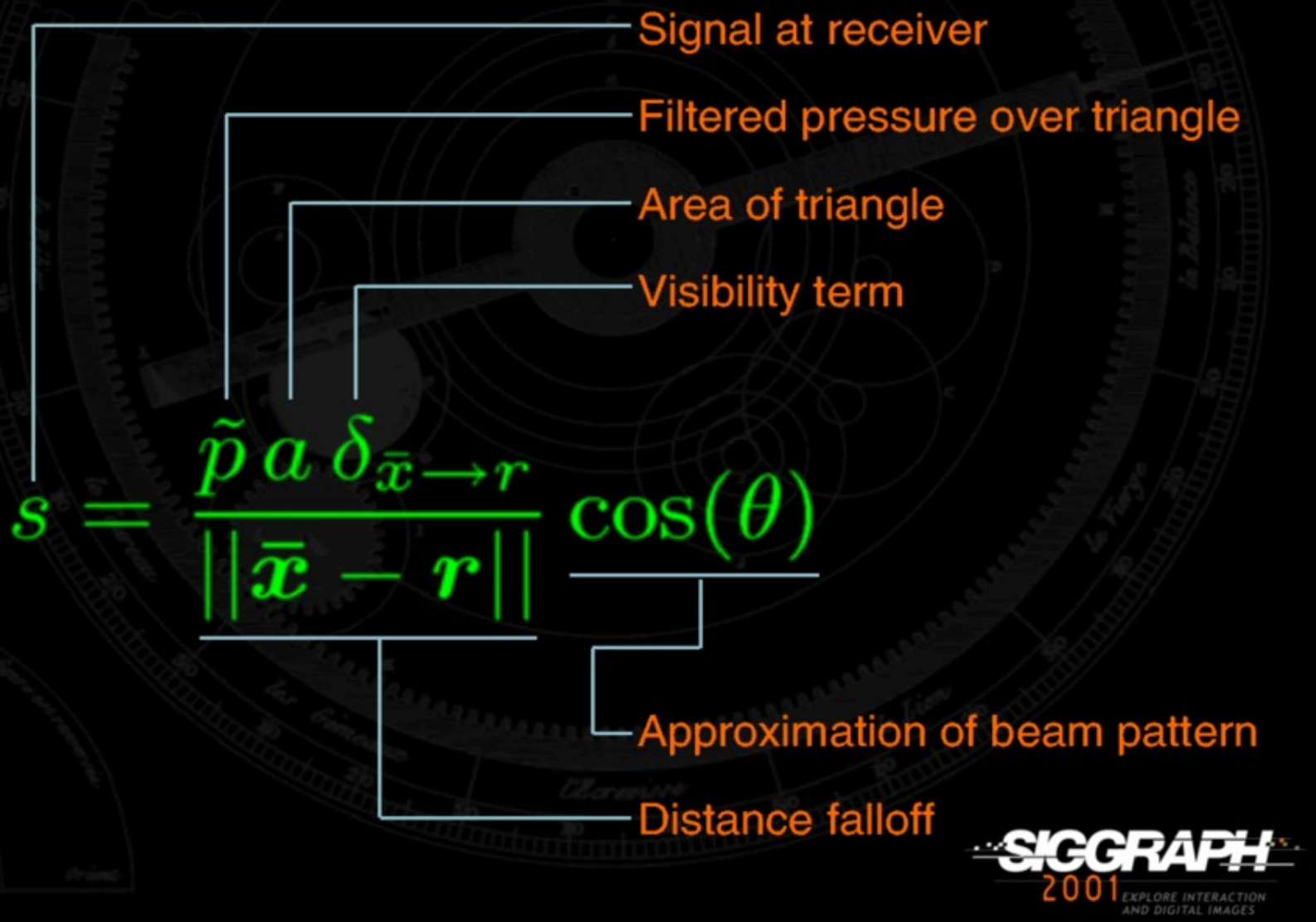
- Model wavefront as sum of simple waves from each triangle (Huygen's principle)





- Simple wave for each triangle face (vibrating piston)

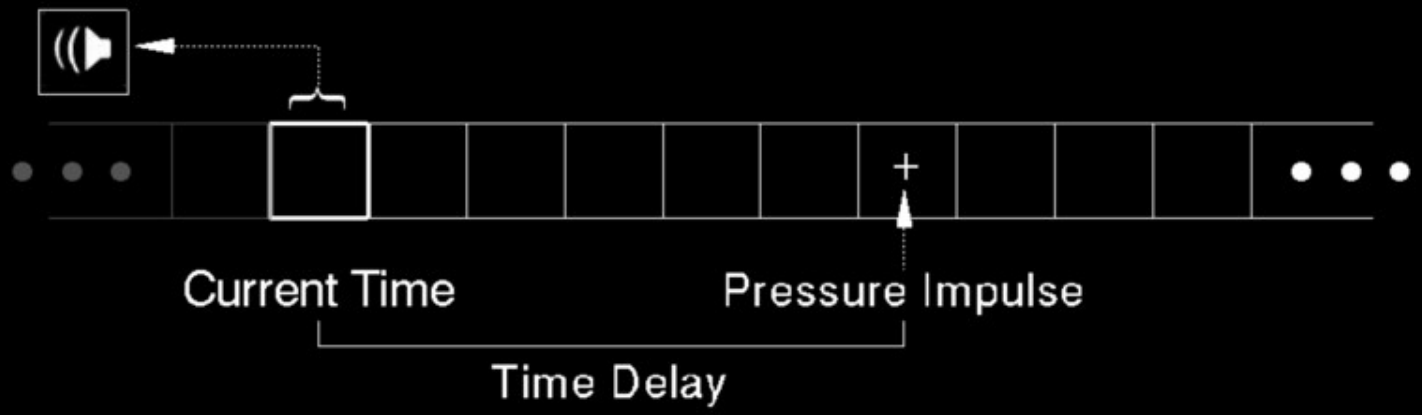
Radiation and Propagation



Radiation and Propagation

- Account for travel time

$$d = \frac{||\bar{x} - r||}{c}$$



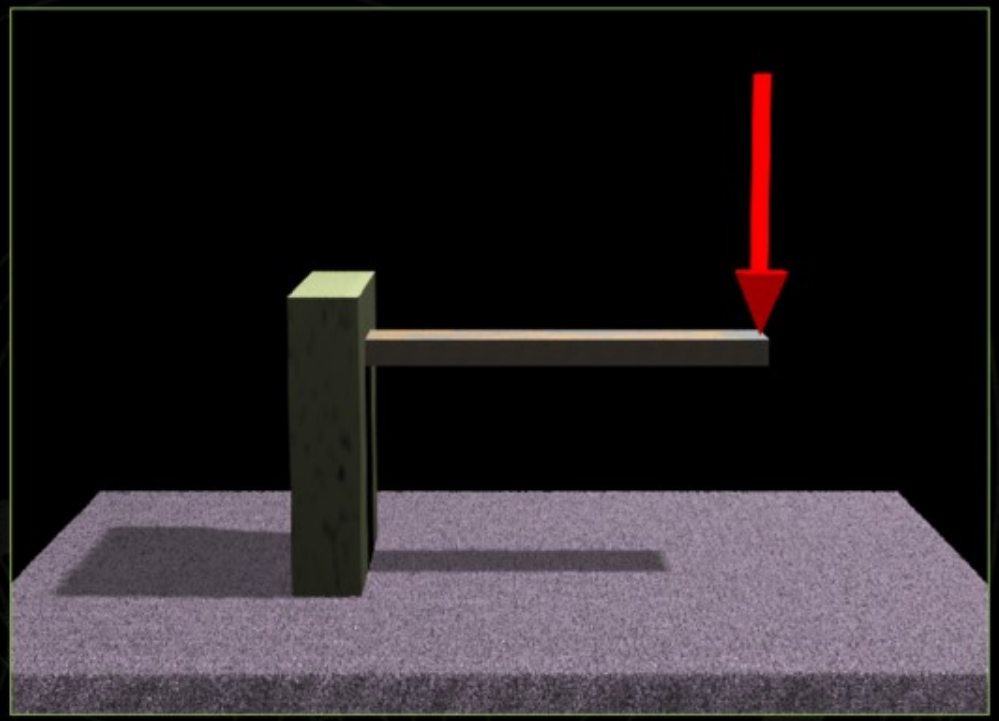
- "Splat" into accumulation buffer

Results

- Stereo from two listener locations
- Omni–directional receivers
- Located at rendering viewpoint
- 20 cm separation perpendicular to viewing and up directions
- 44.1 K Hz audio rate
- Simulation time–step between 10^{-5} and 10^{-7} seconds

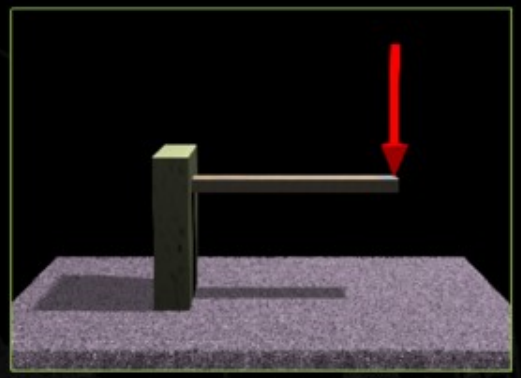
mpg video

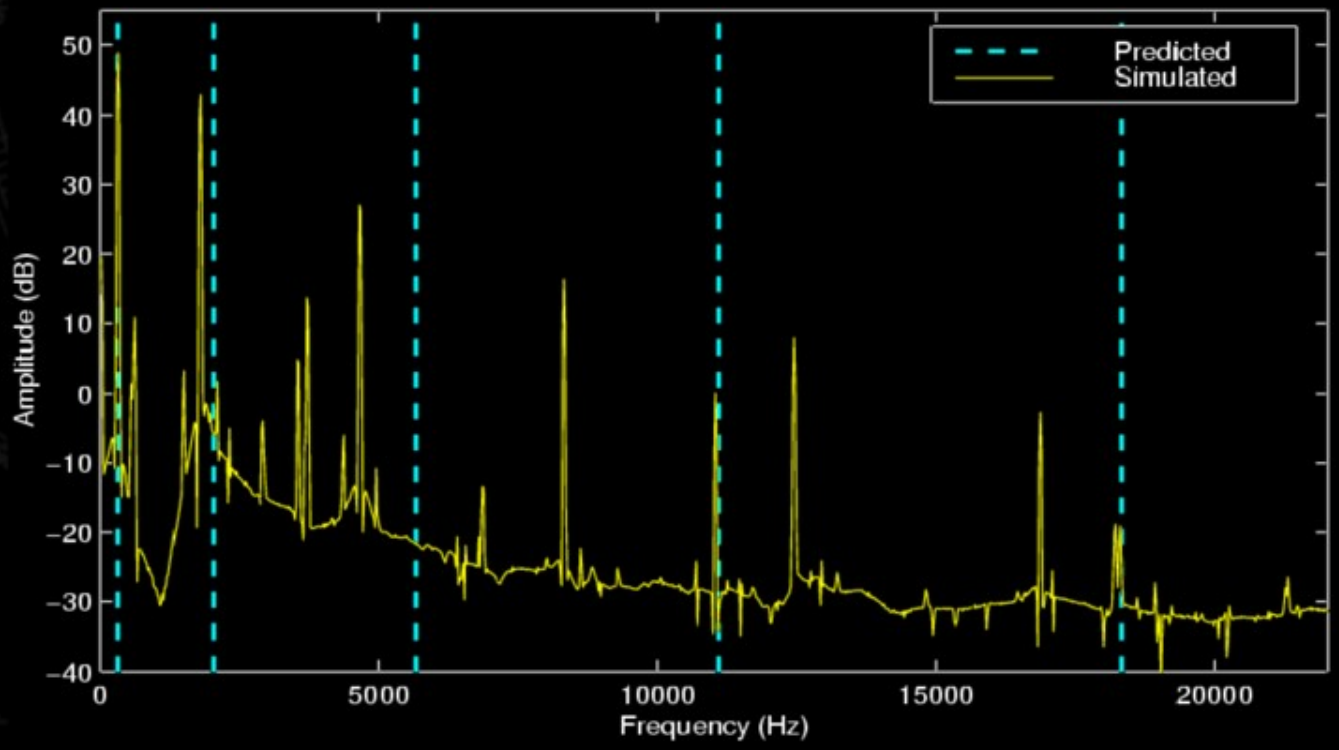
Plucked Bar



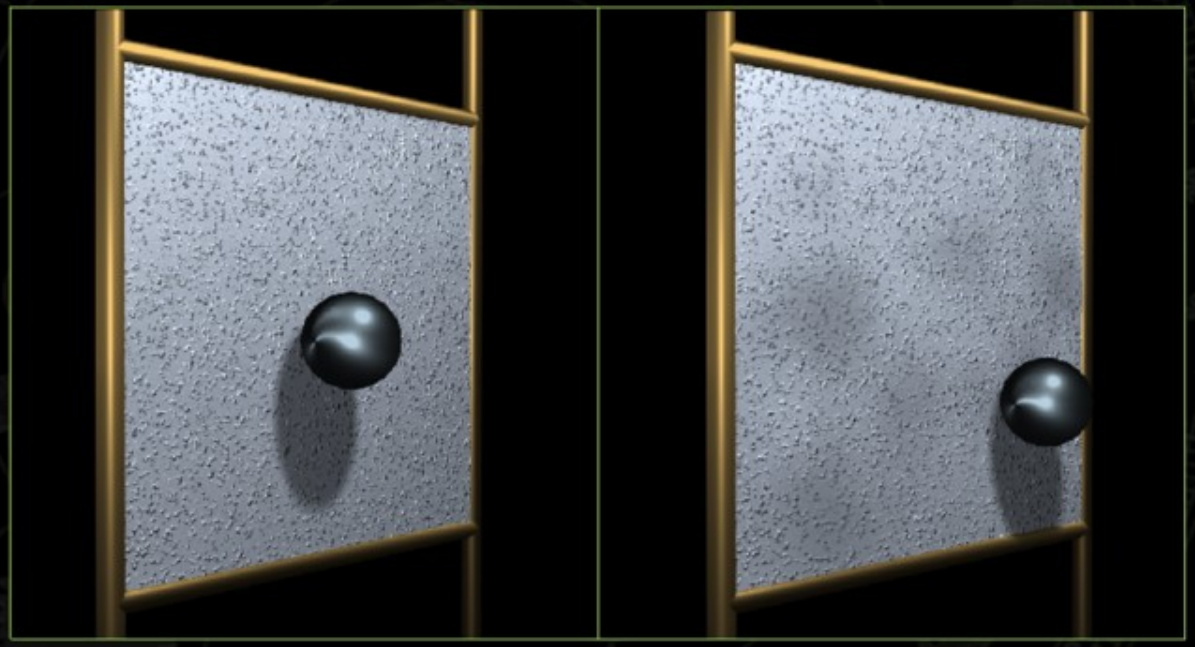
- Fixed at one end
- Impulse applied at the other

Plucked Bar



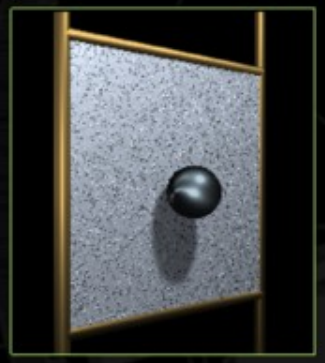

Predicted
Simulated
Amplitude (dB)
50
40
30
20
10
0
−10
−20
−30
−40
0
5000
10000
15000
20000
Frequency (Hz)

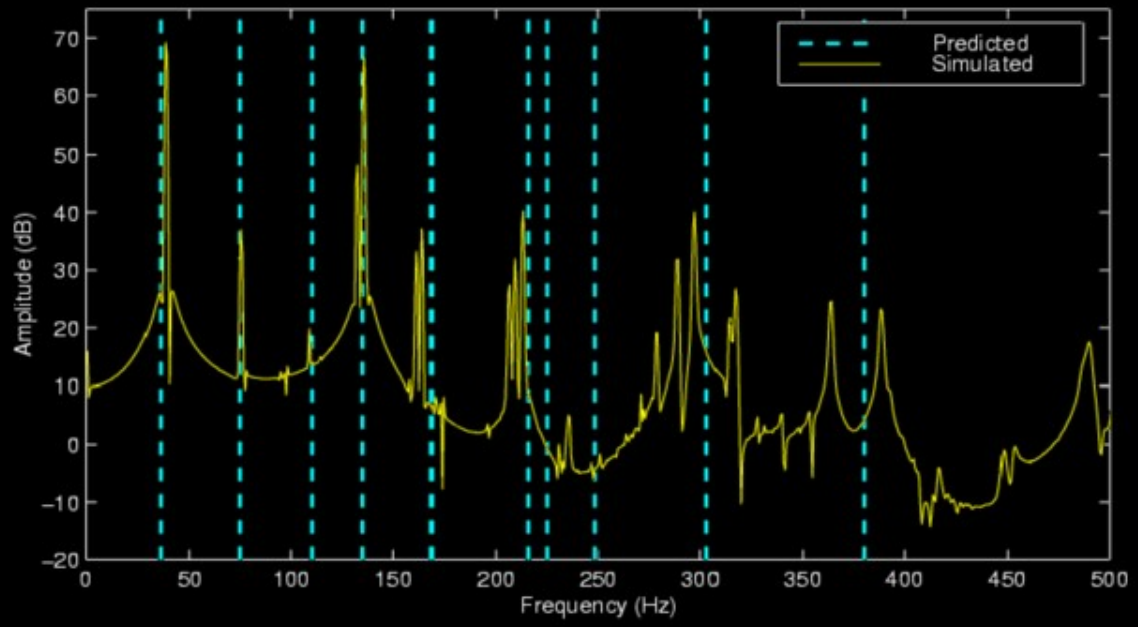
Square Plates

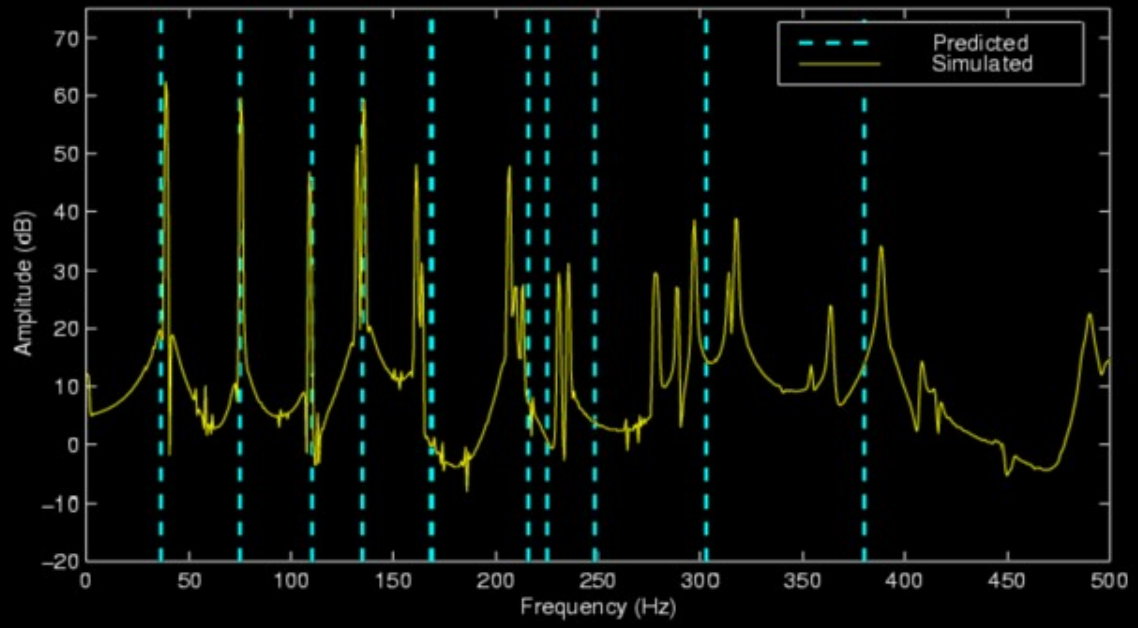


- Fixed along edges
- Struck by mass at different locations

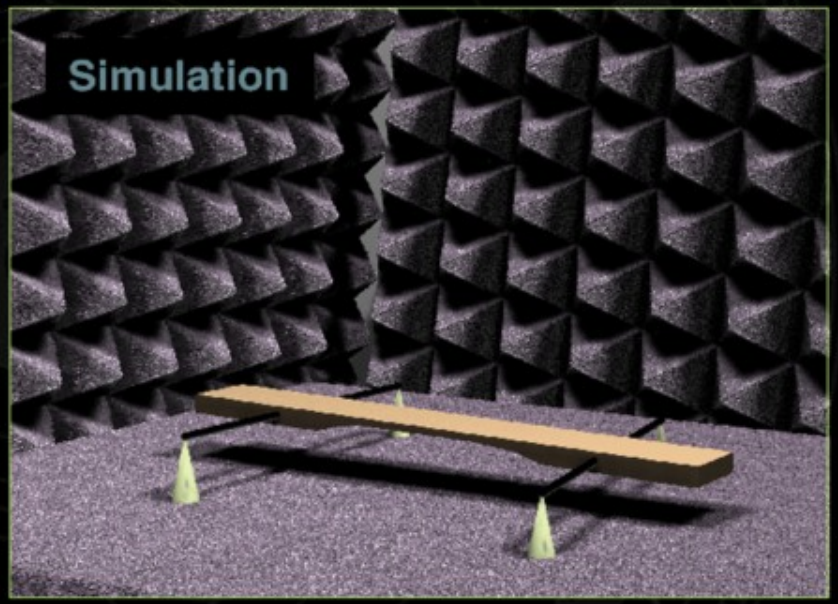
Square Plates





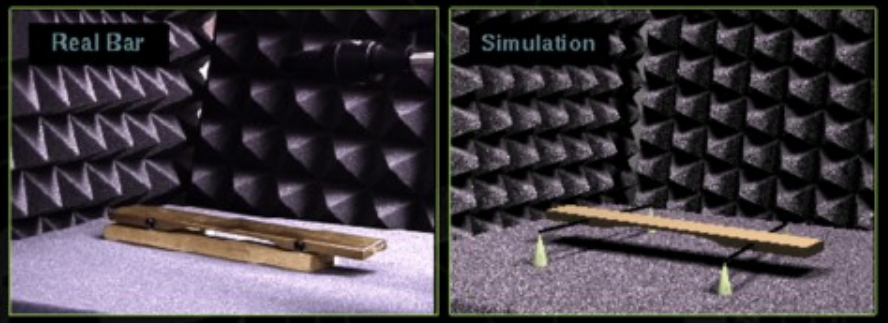


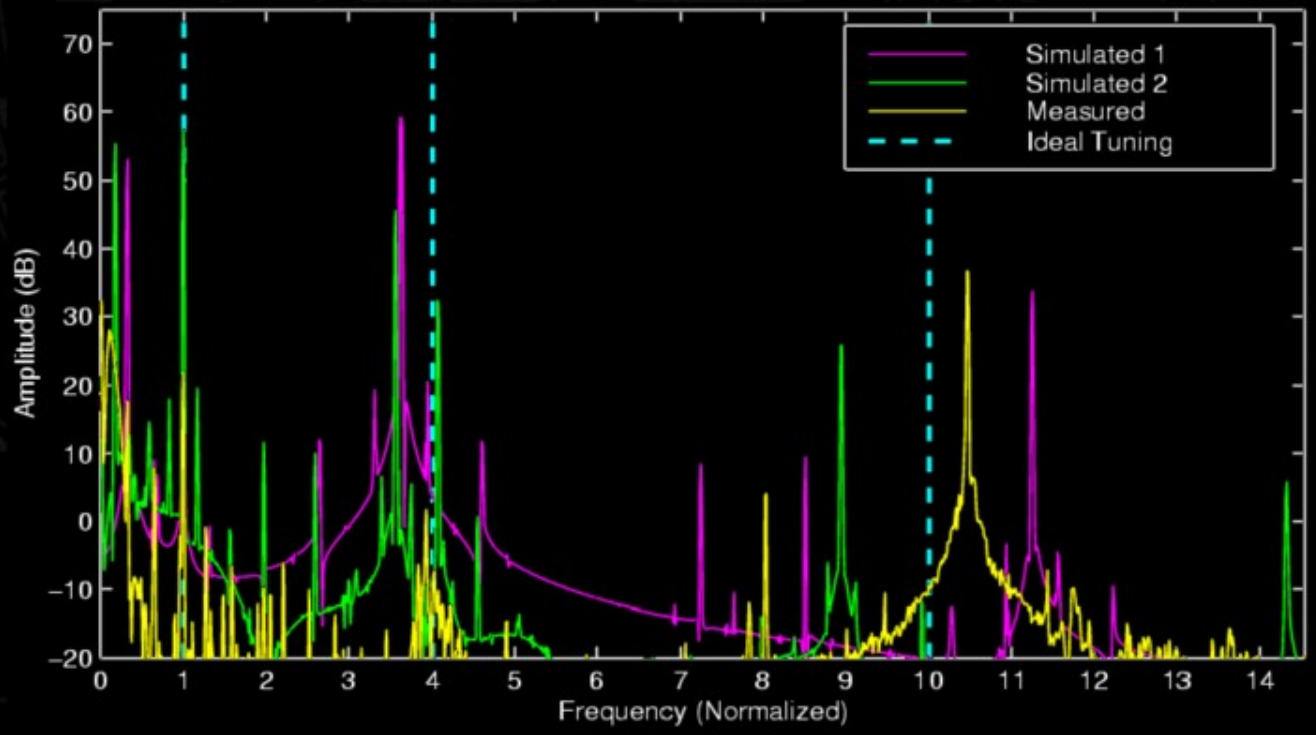
Vibraphone Bar



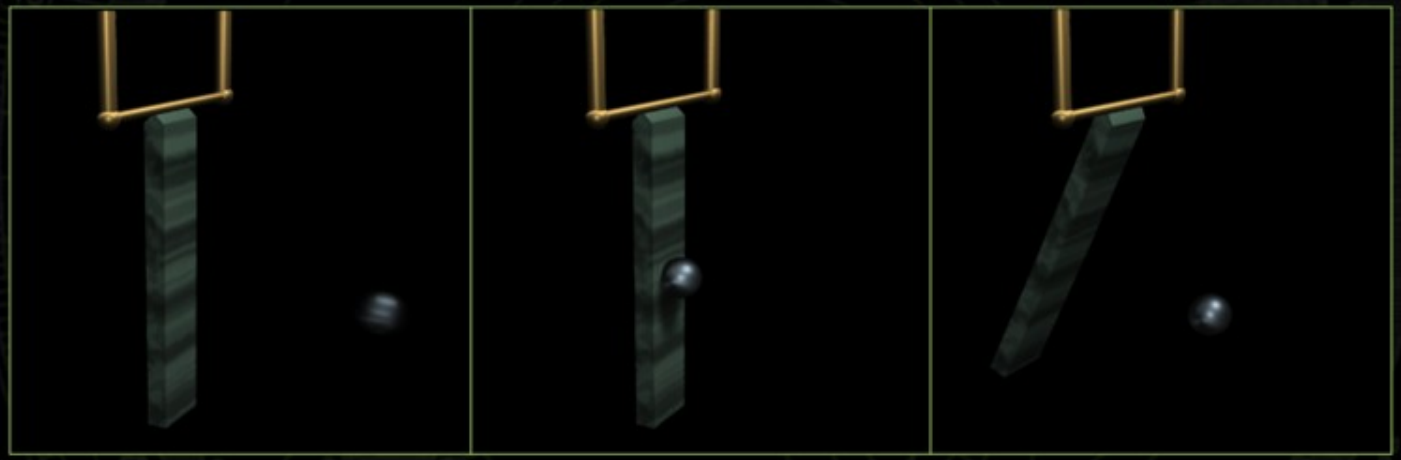
- Spring mounted at nodes of first mode
- Compared to real bar and ideal tunning

Vibraphone Bar



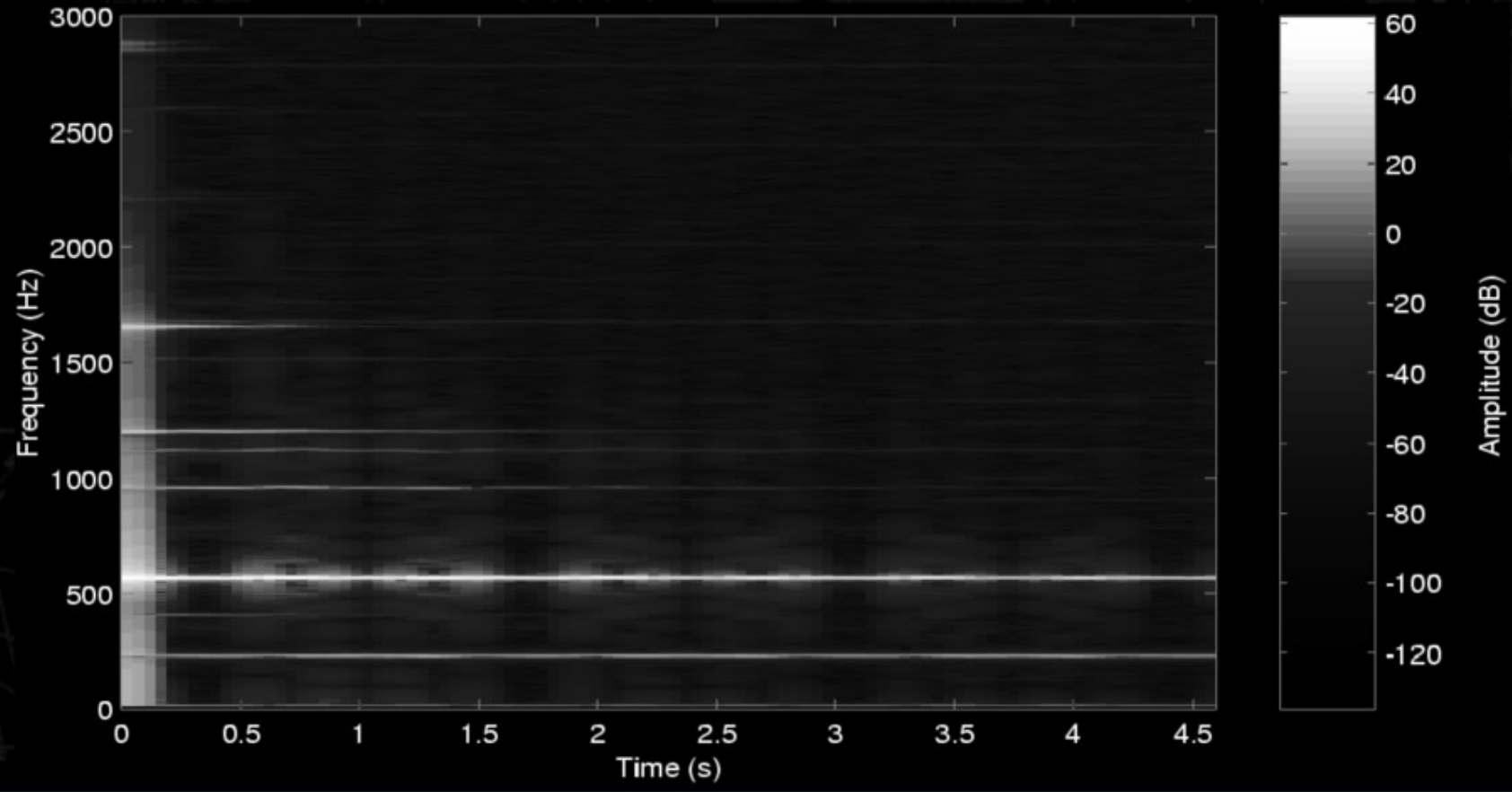


Swinging Bar

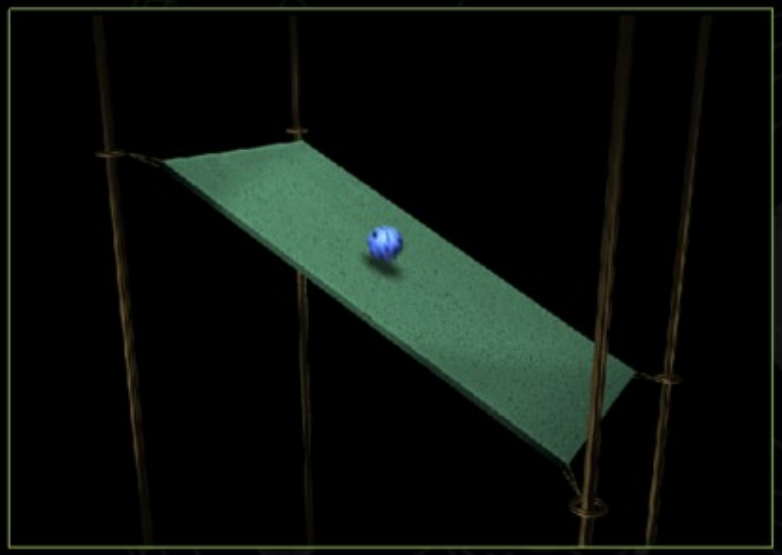


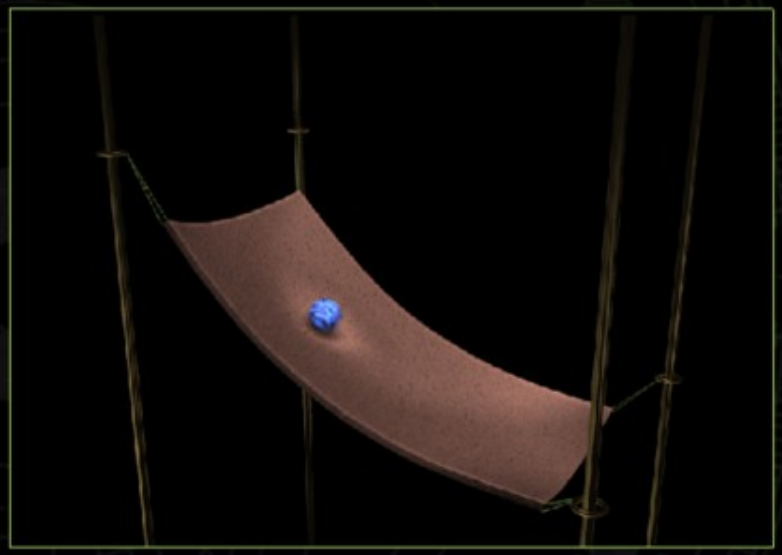
- Doppler effects

Swinging Bar



Slab and Ball



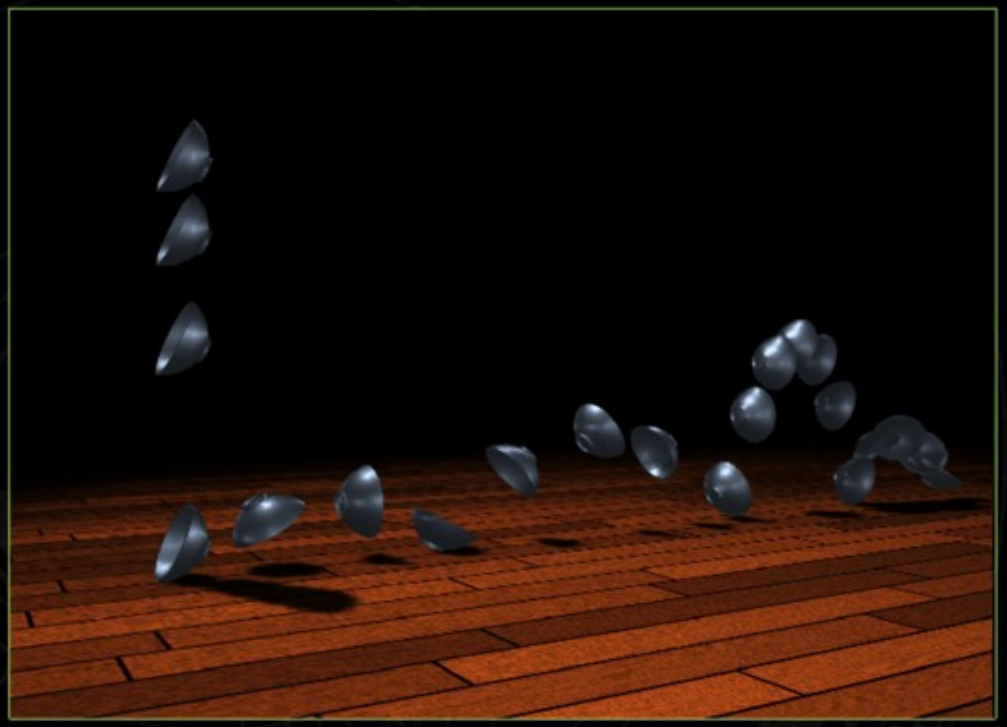


- Both objects sounding
- Mounted on springs

Stiff Sheet

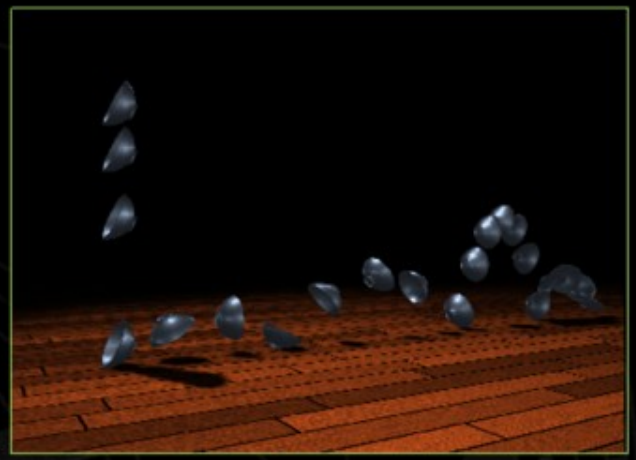
- Non–linear deformation

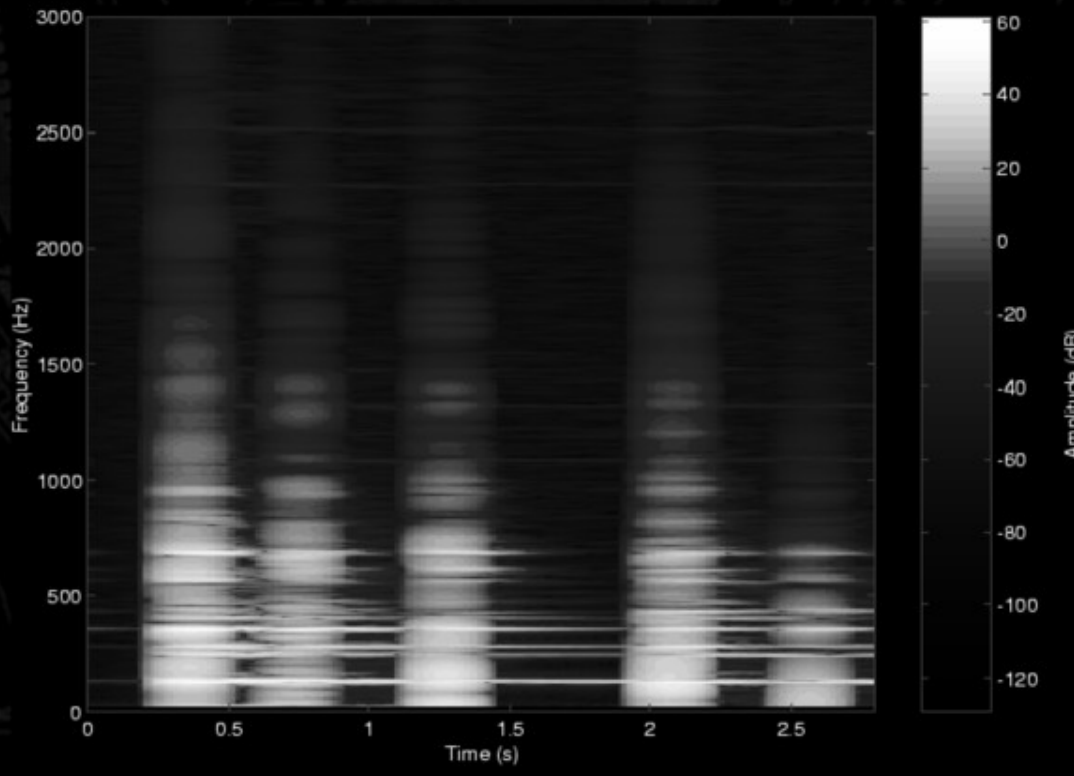
Bowls



- Only bowl is sounding
- Bounces excite different modes

Bowls




3000
2500
2000
1500
1000
500
0
Frequency (Hz)
0
0.5
1
1.5
2
2.5
Time (s)
60
40
20
0
-20
-40
-60
-80
-100
-120
Amplitude (dB)

Future Work

- Other types of simulations
  - Rigid bodies or fluids
  - Large timestep implicit integrators
- Hybrid methods
  - Visual = 60, Tactile = 1500, Audio = 40000
- Better propagation and listener models
- Calibration
- Useful as a debugging tool?


SIGGRAPH
2001
EXPLORE INTERACTION
AND DIGITAL IMAGES